ASTRONOMY

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COLUMBIA UNIVERSITY

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The present condition of astronomic science is a subject too extended to be brought easily within the limits suitable to this occasion; and yet it seems to me pertinent to begin with a seeming prolixity, to make an attempt at answering the question: Why is it desirable to carry on astronomic researches at all? I shall even take the liberty of entering upon this point with some particularity because I desire a test by means of which it may be possible to distinguish between genuine, and therefore desirable researches, and those undertaken mistakenly, through ignorance of any such test, or, worse still, for the mere exploitation of personal reputation and to satisfy the fetish-worship of printed publication.

Perhaps the most important element to consider in forming a judgment of any man's performance is motive. You may commit an act of forgery: it will go unpunished by the law unless a criminal motive can be proved. So I may undertake astronomic researches; I may fail totally; but my efforts will have been justified if my motive was the right one.

Now what is this motive which thus seems to me one essential pre-requisite to genuine research? In a word, it is the same as the motive of the artist. Consciously or unconsciously, the true astronomer strives ever to create a work of art. But what is art, a great painting, sculpture, music, or a monument of architecture? In the last analysis a great painting is but a smeared canvas, sculpture is a chipped

stone, music is a collection of noise, and a monument of architecture is a shelter from the weather. But they are something more than this. He who created them labored and suffered that two or three perhaps in each succeeding generation might take from them that exquisitely subtle emotion that is for him alone who can feel art. The true test of art is its power to give the purest and the noblest pleasure that the mind of man can derive from the work of man; to give this pleasure to the cognoscenti, however few. The ecstasy of the musician, brought about by great music, is identical with the emotion of the mathematician when he studies the works of the masters. If this be true, and it is true, then is mathematics the most sublime of all the arts in that it appeals to the intellect directly; the other arts, like music, require the grosser senses through which to exert their influence. Only, now and again, some rare spirit, such as that which dwelt within the frame of deaf Beethoven, can joy in soundless melodies that breathe amid the crabbed characters of written music, as kindred melodies breathe among the dead equations of astronomy. Therefore I think that researches in science will be written down in the temple of fame if they are inscribed also in the temple of art, and not otherwise.

It is surely impossible to justify these pursuits on any other grounds. The much vaunted search for truth, for the sake of truth,—this, so far as it is other than a manifestation of conscious or unconscious effort to create art, so far is it but an impertinent curiosity to pry into things concealed by nature. Nor can we accept utilitarian value as a sufficient justification. Now I yield to no man in my appreciation of purely utilitarian motives and purely utilitarian results. This I propose to emphasize by describing briefly some of the more important practical applications of astronomy. For my science, more perhaps than any other of the more abstruse sciences, enters most directly, most intimately and

most frequently into the daily life of the people at large. There are at least three practical things that astronomy does for us; and without these modern civilization and modern life would be impossible. The first is the regulation of time. Few persons stop to think how this is done to-day. When we desire to set our watches or clocks aright we simply compare them with an accurate timepiece called a regulator such as may be found in every jeweler's shop. But how does the jeweler regulate his regulator? In every city there is a network of telegraph circuits. One of these is called the "time-wire." For a moderate annual compensation, the telegraph company will run a loop from the time-wire circuit into any building. A telegraphic sounder is attached to this loop, and thus the beats of a standard clock placed in the central office of the telegraph company can be repeated by the sounder for comparison with the jeweler's regulator. By a simple system of omitting one beat before the beginning of each minute, and a different number of beats before the beginning of the hour, it becomes possible to adjust the minute and hour hands of the jeweler's regulator as well as the second hand into accord with the company's standard.

But this simply transfers our problem from the jeweler's regulator to the company's standard, and would be of no use so far as accuracy is concerned, if we had no means of correcting errors in the running of the standard itself. Of course this clock is always made very carefully, and no expense is spared in assuring the greatest precision in all its mechanical parts, so far as precision can be attained by the work of human hands. In spite of all precautions, however, slight errors will occur, and these may accumulate into quantities of quite considerable magnitude as time goes on. To correct them, we must have recourse to a natural standard of time, we must appeal to the stars themselves, and here we need the astronomer.

It is unnecessary at this point to enter into any detailed explanation of how he performs his part of the work. It will suffice to point out that the instruments mounted in any modern permanent observatory enable him to determine the error of his clock within a very few hundredths of a second by an hour's observations on any clear night. A telegraphic comparison with the company's standard then transfers this accurate determination of clock error to the latter instrument, from which it is in turn distributed to the jewelers' regulators, and from them to the people at large. This work is important, essential even; but it requires one astronomer only, very little of his time, is purely routine in character, and cannot be called research in the full sense of the word.

The second definite function of astronomy in practical affairs has to do with navigation. The sure and certain guiding of a ship across the trackless, unmarked ocean is one of the many things startling, even mysterious to the layman, though simple enough to those conversant with the underlying astronomical principles. You will remember that the navigator determines the position of his ship day after day by observations with an astronomical instrument called a sextant. But these observations alone would be of little value. They are but the raw material, and must be subjected to a refining process called "reduction" or computation before they will furnish the information desired. To carry out this process of computation the navigator needs certain printed astronomical tables, that give him the positions of the sun, moon and other heavenly bodies on the sky for every day in the year.

These tables are published by the various civilized governments of the world, and are called Nautical Almanacs. In their preparation we need again the services of one skilled astronomer, to superintend the work, and to assist him a corps of more or less mechanical assistants and clerks.

Like the regulation of time, this work is indispensable, but it is again almost altogether an affair of routine at the present day, and does not partake of the nature of genuine research.

The third practical use of my science to which I shall venture to call your attention has to do with the preparation of maps and charts. The ordinary processes of the surveyor need but to be strengthened by increased power of instruments and increased precision of observation to make them applicable to charting larger portions of the earth's surface, such as an entire continent or the coast lines of a great country. But when such maps and charts have been thus completed, they furnish merely a correct picture of the earth's surface,—showing towns, rivers, bays and capes in their proper relative positions. In this form they are not of any great practical use. To perfect them, it is necessary to mark upon them the latitude and longitude lines, and these cannot be placed correctly without the aid of astronomical observations. The latitudes and longitudes of a number of points covered by the survey must be determined astronomically, and then the proper reference lines can be inscribed on the charts to complete them. I must here once more refrain from a detailed description of modern methods used in this process: it is sufficient to point out that these things too are entirely routine in their character. However important to commercial civilization, they are outside the pale, and seldom come within my notion of what constitutes true research.

This much I have said to show how high an appreciation I have for purely utilitarian motives and purely utilitarian results. Utilitarian motives are not inferior to research; they are not superior to research; they are not equal to research; they are simply other than research.

And now permit me to illustrate my idea still further by describing briefly a modern research that seems to me gen-

uine, absolutely. I select for this purpose a piece of work by Gauss, he who was called, rightly, by those of his contemporaries who were wont to follow the good old custom of writing in the Latin language: Gauss, clarissimus; Gauss, celeberrimus; and, finally, Gauss, incomparabilis.

It was on the very first day of the nineteenth century that Piazzi of Palermo discovered the minor planet Ceres, the first to be added to the seven previously well known. Illness prevented Piazzi from observing the new object during more than six weeks; and as news of planetary discovery traveled slowly in those days, it was not until the latter part of March that astronomers in northern Europe heard of the new object. By that time Ceres had passed so near the sun that it could not be observed, and great excitement resulted from the fear that it would never again be found, because astronomers would not know exactly where to look for it when the time should again come to attempt observation.

And there was good reason for this fear. The older planets had of course been observed throughout many orbital revolutions, and it was a difficult, unsolved problem to determine the path of such a moving body when the available observations extended through a very small fraction only of the planet's total circuit around the sun. Without a satisfactory solution of the problem, a further search would be well-nigh hopeless when it should again become possible to undertake one. Gauss was then a young man of twenty-three at Göttingen. He attacked the difficulty, overcame it, and his computations made the re-discovery of Ceres easy in the following December. He had produced his deathless work on the theory of motion, but he spent eight long years perfecting it before he gave it to the press. When it appeared, the world possessed one more true work of art. Fallible and imperfect must ever be the results of

human effort. No one can reach his ideal. But the *Theoria Motus* stands immaculate, unapproachable, such as might be a marble of Phidias; none have since added anything to it. This is in truth a hall-mark of art, that the thing itself shall approximate perfection, shall be the utmost effort of the utmost man.

And now let me contrast with this another modern research that seems to illustrate the kind of scientific work sometimes undertaken in ignorance of the true test of value. I refer to the canals of Mars. By no conceivable possibility can this work convey to any one an impression of life everlasting. About it all is an air of unreality; one feels almost as if mankind would forget it before actually becoming aware of its existence. The strongest argument in favor of Martian canals is the intense desire of certain human beings to know other planets inhabited.

If I may be permitted to do so, I should like to turn aside here for a moment, and inquire what we mean by *seeing* a thing. What is the actual process? Light waves coming from the object under examination travel through the luminiferous ether, and finally impinge upon the outer surface of the eye, like surf breaking on an ocean shore. They are concentrated or brought to a focus by the lens in our eye, and produce some kind of an effect which we do not quite understand upon the rods and cones of the retina. This results in an impression being received by the brain, via the optic nerve. The brain in its turn does an unexplained something with this impression; what we think we see is equal to that which came through the eye and optic nerve plus what the brain does to it on its arrival at headquarters. It is this little *plus*, I fear, that has helped to create the Martian canals and especially the intelligent engineers who built them. The human brain cannot distinguish between that which comes through the optic nerve, and that which the brain adds to it. The sum is what we seem to see.

Once started on the downward path of discovery, the rest is easy. We see what we desire and hope to see; do what we will we cannot prevent this; as Shakespeare says: "Increase of appetite had grown by what it fed on."

Again, people are very apt to think they see what they are told by others is to be seen. Not many years ago a shipful of astronomical tourists was sent out from this country to one of the Norway fjords, where an eclipse of the sun was to occur. An unfortunate astronomical lecturer accompanied the expedition charged with the duty of delivering two addresses to the ship's company. One of these was to precede the eclipse, to tell the people what they were about to see; the other was to follow the phenomenon, to tell them what they had seen. This seems an admirable arrangement, probably devised by some one who knew well the psychology of the matter.

If the substratum of observed facts is abandoned,—and I think most of it will be abandoned when we come to compare impartially the drawings and photographs made by various observers,—it becomes useless to point out contradictions and improbabilities in the dream-fabric of theory built upon it. I can summarize for you several bookfuls of Martian knowledge very briefly thus: certain observers think they see some rather hazy markings on the planet. That is all there is to it.

And now permit me to devote the few minutes of your time still remaining at my disposal to one or two of the more important problems now pending before astronomers. I shall avail myself to a limited extent of Förster's admirable division of the subject into three parts, astromechanics, astrometry, and astrophysics. The first of these deals with the mechanical laws of motion based on the theory of gravitation, the precession of the equinoxes, the nutation of the earth's axis, planetary perturbations, etc. The second has to do rather with the actual measurement

of objects in the heavens, their sizes and relative positions on the sky. The third studies the physical nature of celestial bodies and determines the chemical elements of which they consist.

As before, the stern necessity for brevity compels me to limit myself strictly to the most important part of my subject: I therefore select astro-mechanics, and under that head cannot do better than call your attention to the present attitude of astronomers toward the law of gravitation itself. This law declares that every particle of matter in the universe attracts every other particle of matter. The precise conditions under which such attraction is supposed to have effect I disregard for the moment as a matter of detail. But is there really such a thing as gravitation? Has this law a real physical existence, and does it actually hold sway in our world? In the first place, the law itself is contrary to ordinary ideas of common sense. How can any particle of matter pull any other particle, when there is no connecting link through which the pull can be exerted? This objection we may pass over because we can accept the law even though we are unable to understand just how or why it exists and acts. The question is, to what extent does it enable us to explain for the past and predict for the future all those intricate convolutions of motive that we observe among the planetary bodies in our solar system and even among the distant congeries of stars.

It is a singular fact that all these motions can be thus explained for the past and predicted for the future without using the law of gravitation, yet with an accuracy as great as this law itself renders possible. Existing tables of planetary and lunar motion have been computed by the aid of certain formulas obtained from the law of gravitation by means of mathematical analysis. These formulas consist of a long series of parts or "terms" which must be computed separately and the results added in order to find the

planet's position on the sky to be printed in the nautical almanacs to which I have already made reference and subsequently compared with actual observation for a verification of theoretical law.

Now all these terms are what mathematicians call *periodic* in form. This means that while any given term may increase as time goes on, such increase cannot continue without limit. There must come an epoch when it will again begin to decrease, and so on alternately to the end of time. It was on this peculiarity of periodicity that Laplace based his famous but not quite rigorous mathematical demonstration of stability in our solar system. All terms in all motions being strictly periodic, it follows that all changes in the system are likewise periodic. No matter how intricate may be the changes occurring in the system, these cannot continue indefinitely, and everything must return again to its original form and condition after the lapse of sufficient ages of time.

But the very fact of uniform periodicity in these terms brings out a most curious circumstance. The ancient Ptolemaic theory of the universe was periodic too. Ptolemy made the earth immobile, and all orbits were circular. The revolving planet did not travel in the original circle, but upon the circumference of a second smaller circle, perhaps, whose centre moved in the original curve. Now if we apply modern mathematical methods to Ptolemy's theory of the universe, it is possible to show that we can thus reproduce all Laplace's periodic terms by simply postulating a sufficient number of these circles moving one upon the other. For each term in Laplace's series we must have one more Ptolemaic circle. This having been done, the actual formulas to be used in the computation of a planet's place in the sky become identical, whether we deduce them by the methods of Newton and Laplace or from the principle of Ptolemy. Consequently, the agreement between theory

and observation is the same either way; and such agreement fails as a test to determine whether Ptolemy or Newton had a correct theory of the universe. The one thing that leads us to accept Newton's law of gravitation is that this law is extremely simple compared with those intricacies of endless eccentric circles. And the human mind chooses to assume that the universe is constructed on a simple plan rather than an extremely complicated one. Thus gravitation rests ultimately to some extent on a mere peculiarity of the human mind.

Now I have no desire to be made, to-night, the subject of an Associated Press dispatch, in which I shall be heralded throughout this land as having abandoned the law of gravitation, and returned to the old Ptolemaic theory of the universe. I therefore state explicitly that such is not the case. I have merely called attention to the above interesting facts, in order that I may mention what is the last word of science on this matter. We cannot do better than seek it in Simon Newcomb's 1895 memoir entitled "The elements of the four inner planets and the fundamental constants of astronomy."

Newton, as you know, postulated that the attraction of gravity diminishes proportionately with the square of the distance. If a body pulls another with a certain strength at a certain distance, then this pull will be diminished to one-fourth its former force if the distance between the bodies be doubled. Now there exist certain outstanding discrepancies between observed and computed motions which have never been explained satisfactorily. This does not necessarily prove that the law of gravitation is non-existent, because the failure in explanation may be due simply to the feebleness of man's mathematical powers. Something may have been overlooked somewhere in the endless and seemingly inextricable complexities of mathematical deductions. But this is improbable too; for you

may well imagine that no stone has been left unturned by successive generations of able investigators.

For this reason it has been proposed to alter the law of gravitation slightly, so as to explain these little theoretical discrepancies. The proposition is to suppose the attraction to diminish, not as the square of the distance, but in a manner differing very slightly from the square. This I may call the law of modified gravitation. To Newcomb the hypothesis seems "provisionally not inadmissible," and more unobjectionable than others that have been proposed. But in abandoning the Newtonian form of the law we lose its simplicity; which, as I have said, seems to be the strongest argument for its reality.

In the light of Newcomb's dicta, we must to-day characterize Newton's law as a working hypothesis merely, and one that even as such is open to some doubt. I can tell you nothing that more strongly emphasizes the mutable and perishable character of results attained by the human intellect nor anything that better illustrates the ideas with which I began my address. But this mutability and this perishability exist for the materialist only. Newton's law, like Ptolemy's cycles, may in time pass completely out of practical use, may cease to be a part of the active machinery of science; but Newton's law and Ptolemy's epicycles will surely, both alike, endure for evermore as works of art.